CHAPTER 12

INTERNAL COMBUSTION ENGINE

CHAPTER LEARNING OBJECTIVES

Upon completion of this chapter, you should be able to do the following:

- *Explain the principles of a combustion engine.*

- *Explain the process of an engine cycle.*

- *State the classifications of engines.*

- *Discuss the construction of an engine.*

- *List the auxiliary assemblies of an engine.*

The automobile is a familiar object to all of us. The engine that moves it is one of the most fascinating and talked about of all the complex machines we use today. In this chapter we will explain briefly some of the operational principles and basic mechanisms of this machine. As you study its operation and construction, notice that it consists of many of the devices and basic mechanisms covered earlier in this book.

COMBUSTION ENGINE

We define an engine simply as a machine that converts heat energy to mechanical energy. The engine does this through either internal or external combustion.

Combustion is the act of burning. Internal means inside or enclosed. Thus, in internal combustion engines, the burning of fuel takes place inside the engine; that is, burning takes place within the same cylinder that produces energy to turn the crankshaft. In external combustion engines, such as steam engines, the burning of fuel takes place outside the engine. Figure 12-1 shows, in the simplified form, an external and an internal combustion engine.

The external combustion engine contains a boiler that holds water. Heat applied to the boiler causes the water to boil, which, in turn, produces steam. The steam passes into the engine cylinder under pressure and forces the piston to move downward. With the internal
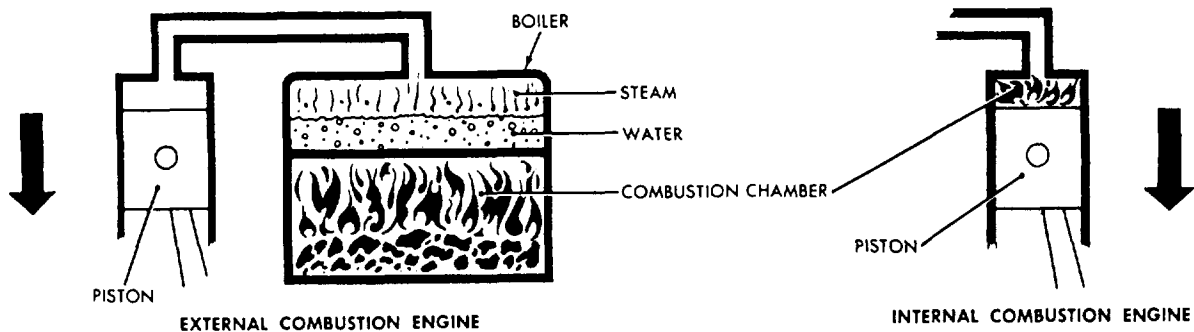

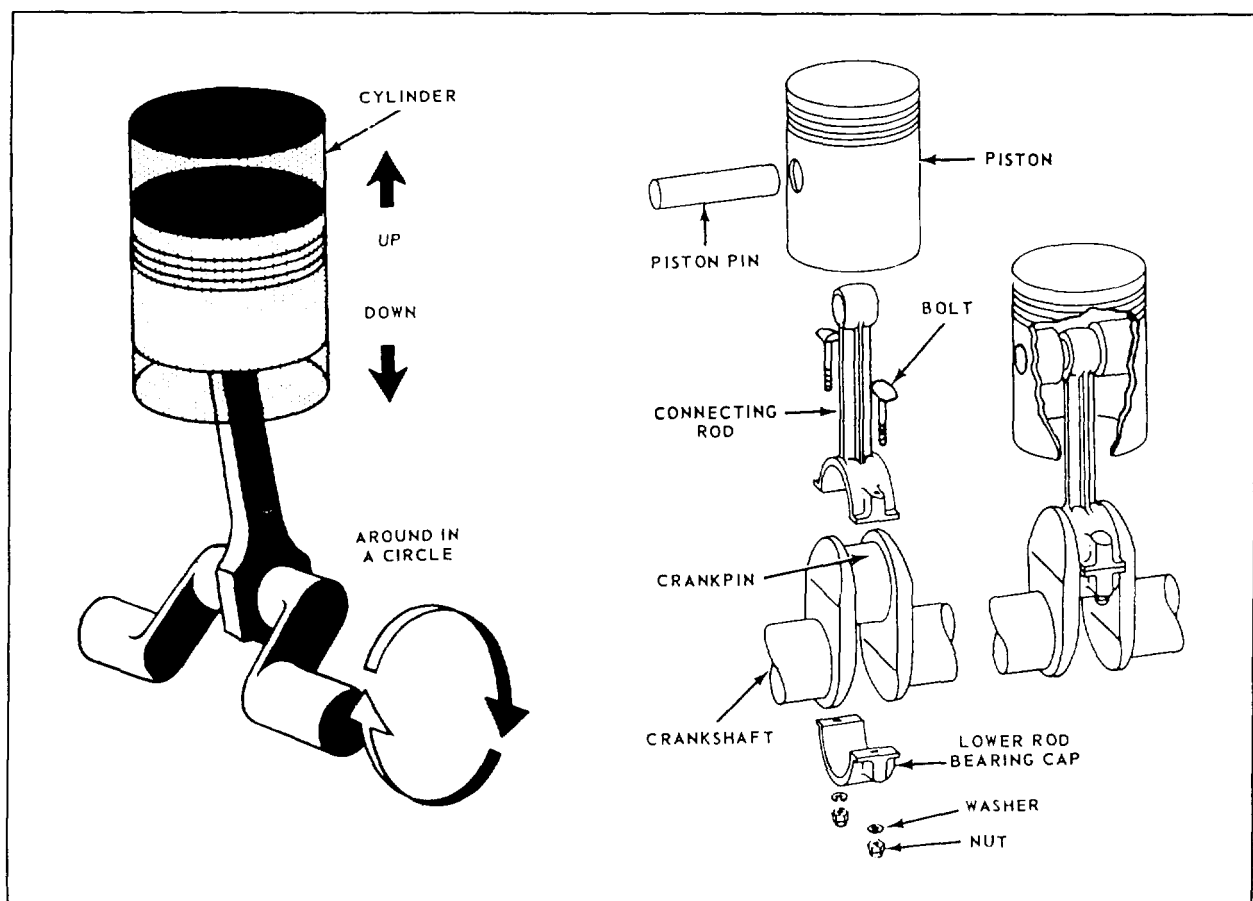Figure 12-1.-Simple external and internal combustion engine.

Figure 12-2.-Cylinder, piston, connecting rod, and crankshaft for a one-cylinder engine.

combustion engine, the combustion takes place inside the cylinder and is directly responsible for forcing the piston to move downward.

The change of heat energy to mechanical energy by the engine is based on a fundamental law of physics. It states that gas will expand upon the application of heat. The law also states that the compression of gas will increase its temperature. If the gas is confined with no outlet for expansion, the application of heat will increase the pressure of the gas (as it does in an automotive cylinder). In an engine, this pressure acts against the head of a piston, causing it to move downward.

As you know, the piston moves up and down in the cylinder. The up-and-down motion is known as reciprocating motion. This reciprocating motion (straight line motion) must change to rotary motion (turning motion) to turn the wheels of a vehicle. A crank and a connecting rod change this reciprocating motion to rotary motion.

All internal combustion engines, whether gasoline or diesel, are basically the same. They all rely on three elements: air, fuel, and ignition.

Fuel contains potential energy for operating the engine; air contains the oxygen necessary for combustion; and ignition starts combustion. All are fundamental, and the engine will not operate without any one of them. Any discussion of engines must be based on these three elements and the steps and mechanisms involved in delivering them to the combustion chamber at the proper time.

DEVELOPMENT OF POWER

The power of an internal combustion engine comes from the burning of a mixture of fuel and air in a small, enclosed space. When this mixture burns, it expands; the push or pressure created then moves the piston, thereby cranking the engine. This movement is sent back to the wheels to drive the vehicle.
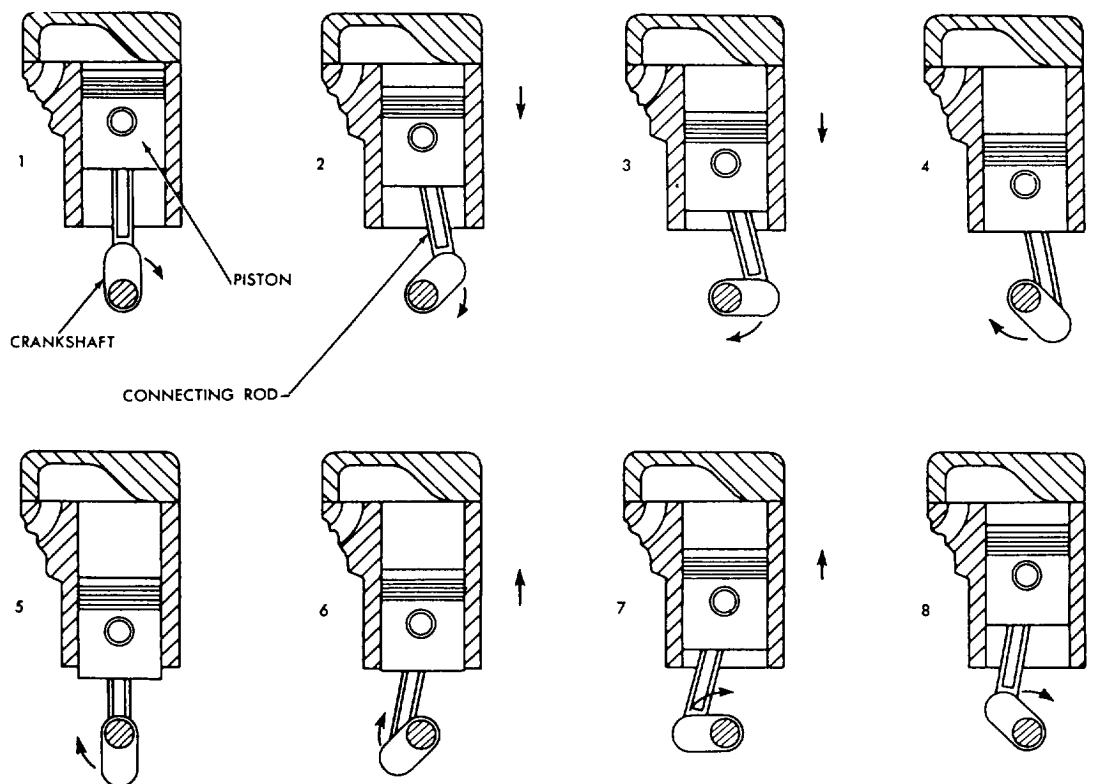
Figure 12-3.-Relationship of piston, connecting rod, and crank on crankshaft as crankshaft turns one revolution.

Since similar action occurs in all cylinders of an engine, we will describe the use one cylinder in the development of power. The one-cylinder engine consists of four basic parts: cylinder, piston, connecting rod, and crankshaft (shown in fig. 12-2).

The cylinder, which is similar to a tall metal can, is closed at one end. Inside the cylinder is the piston, a movable metal plug that fits snugly into the cylinder, but can still slide up and down easily. This up-and-down movement, produced by the burning of fuel in the cylinder, results in the production of power from the engine.

You have already learned that the up-and-down movement is called reciprocating motion. This motion must be changed to rotary motion to rotate the wheels or tracks of vehicles. This change is accomplished by a crank on the crankshaft and a connecting rod between the piston and the crank.

The crankshaft is a shaft with an offset portion-the crank— that describes a circle as the shaft rotates. The top end of the connecting rod connects to the piston and must therefore go up and down. Since the lower end of the connecting rod attaches to the crankshaft, it moves in a circle; however it also moves up and down.

When the piston of the engine slides downward because of the pressure of the expanding gases in the cylinder, the upper end of the connecting rod moves downward with the piston in a straight line. The lower end of the connecting rod moves down and in a circular motion at the same time. This moves the crank; in turn, the crank rotates the shaft. This rotation is the desired result. So remember, the crankshaft and connecting rod combination is a mechanism for changing straight-line, up-and-down motion to circular, or rotary, motion.

BASIC ENGINE STROKES

Each movement of the piston from top to bottom or from bottom to top is called a stroke. The piston takes two strokes (an upstroke and a downstroke) as the crankshaft makes one complete revolution. When the piston is at the top of a stroke, it is said to be at top dead center. When the piston is at the bottom of a stroke, it is said to be at bottom dead center. These positions are rock positions, which we will discuss further in this chapter under "Timing." See figure 12-3 and figure 12-7.

The basic engine you have studied so far has had no provisions for getting the fuel-air mixture into the cylinder or burned gases out of the cylinder. The

INTAKE

EXHAUST VALVE CLOSED

FUEL-AIR MIXTURE ENTERING CYLINDER

AIR ENTERING CARBURETOR

PISTON MOVING DOWN

FUEL DISCHARGING FROM CARBURETOR NOZZLE

INTAKE VALVE OPEN

VALVE TAPPET LIFTING VALVE

CAM LOBE LIFTING VALVE TAPPET

COMPRESSION

FUEL-AIR MIXTURE BEING COMPRESSED

BOTH VALVES CLOSED

PISTON MOVING UP

POWER

SPARK INTAKE IGNITES MIXTURE

BOTH VALVES CLOSED

PISTON MOVING DOWN

EXHAUST

EXHAUST VALVE OPEN

INTAKE VALVE CLOSED

PISTON MOVING UP

VALVE TAPPET LIFTING VALVE
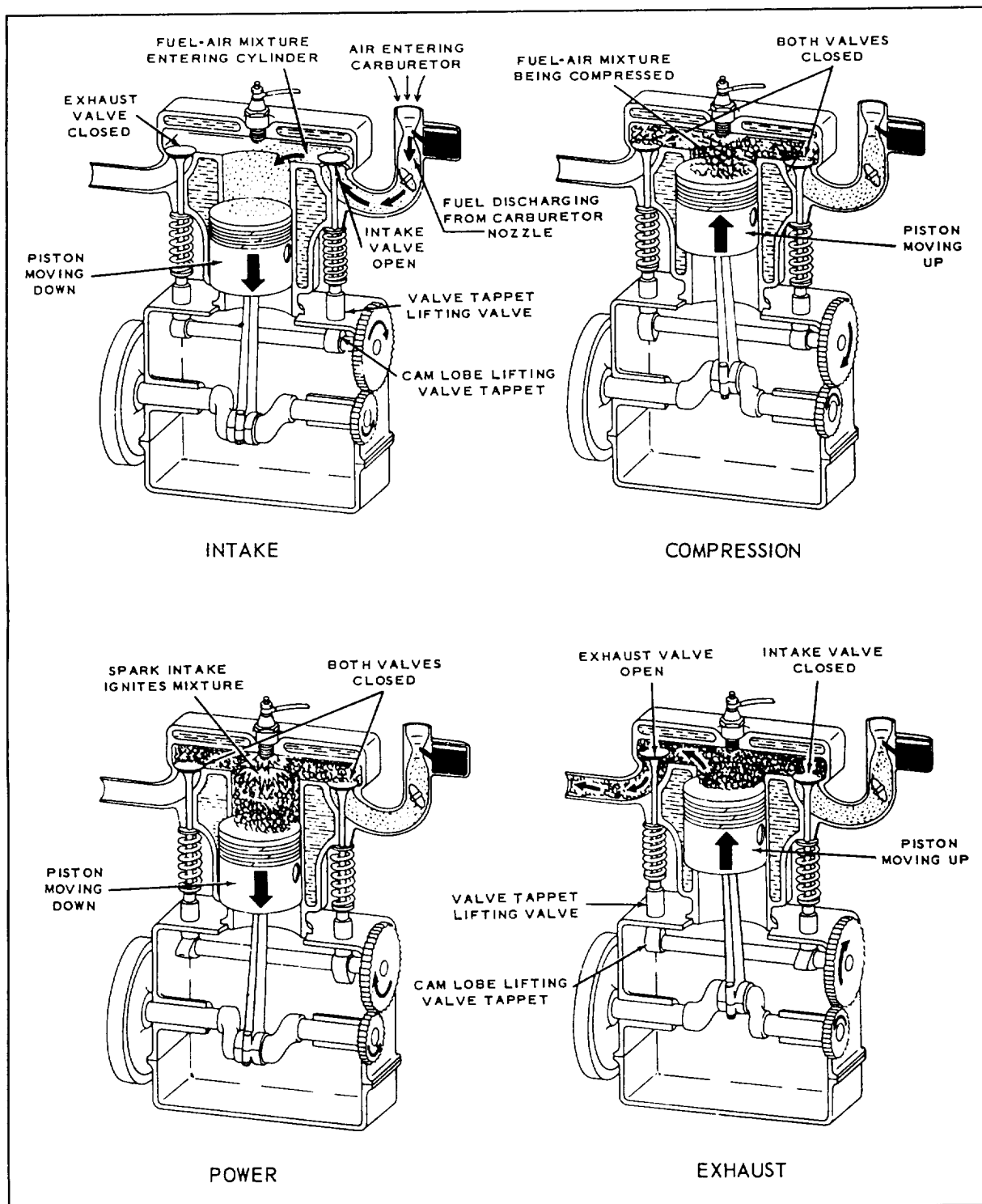
CAM LOBE LIFTING VALVE TAPPET

Figure 12-4.-Four-stroke cycle in a gasoline engine.

enclosed end of a cylinder has two openings. One of the openings, or ports, permits the mixture of air and fuel to enter, and the other port permits the burned gases to escape from the cylinder. The two ports have valves assembled in them. These valves, actuated by the camshaft, close off either one or the other of the ports, or both of them, during various stages of engine operation. One of the valves, called the intake valve, opens to admit a mixture of fuel and air into the cylinder. The other valve, called the exhaust valve, opens to allow the escape of burned gases after the fuel-and-air mixture has burned. Later you will learn more about how these valves and their mechanisms operate.

The following paragraphs explain the sequence of actions that takes place within the engine cylinder: the intake stroke, the compression stroke, the power stroke, and the exhaust stroke. Since these strokes are easy to identify in the operation of a four-cycle engine, that engine is used in the description. This type of engine is called a four-stroke-Otto-cycle engine, named after Dr. N. A. Otto who, in 1876, first applied the principle of this engine.

INTAKE STROKE

The first stroke in the sequence is the intake stroke (fig. 12-4). During this stroke, the piston is moving downward and the intake valve is open. This downward movement of the piston produces a partial vacuum in the cylinder, and air and fuel rush into the cylinder past the open intake valve. This action produces a result similar to that which occurs when you drink through a straw. You produce a partial vacuum in your mouth, and the liquid moves up through the straw to fill the vacuum.

COMPRESSION STROKE

When the piston reaches bottom dead center at the end of the intake stroke (and is therefore at the bottom of the cylinder) the intake valve closes and seals the upper end of the cylinder. As the crankshaft continues to rotate, it pushes the connecting rod up against the piston. The piston then moves upward and compresses the combustible mixture in the cylinder. This action is known as the compression stroke (fig. 12-4). In gasoline engines, the mixture is compressed to about one-eighth of its original volume. (In a diesel engine the mixture may be compressed to as little as one-sixteenth of its original volume.) This compression of the air-fuel mixture increases the pressure within the cylinder. Compressing the mixture in this way makes it more combustible; not only does the pressure in the cylinder go up, but the temperature of the mixture also increases.

POWER STROKE

As the piston reaches top dead center at the end of the compression stroke (and is therefore at the top of the cylinder), the ignition system produces an electric spark. The spark sets fire to the fuel-air mixture. In burning, the mixture gets very hot and expands in all directions. The pressure rises to about 600 to 700 pounds per square inch. Since the piston is the only part that can move, the force produced by the expanding gases forces the piston down. This force, or thrust, is carried through the connecting rod to the crankpin on the crankshaft. The crankshaft is given a powerful twist. This is known as the power stroke (fig. 12-4). This turning effort, rapidly repeated in the engine and carried through gears and shafts, will turn the wheels of a vehicle and cause it to move along the highway.

EXHAUST STROKE

After the fuel-air mixture has burned, it must be cleared from the cylinder. Therefore, the exhaust valve opens as the power stroke is finished and the piston starts back up on the exhaust stroke (fig. 12-4). The piston forces the burned gases of the cylinder past the open exhaust valve. The four strokes (intake, compression, power, and exhaust) are continuously repeated as the engine runs.

ENGINE CYCLES

Now, with the basic knowledge you have of the parts and the four strokes of the engine, let us see what happens during the actual running of the engine. To produce sustained power, an engine must repeatedly complete one series of the four strokes: intake, compression, power, and exhaust. One completion of this series of strokes is known as a cycle.

Most engines of today operate on four-stroke cycles, although we use the term *four-cycle engines* to refer to them. The term actually refers to the four strokes of the piston, two up and two down, not the number of cycles completed. For the engine to operate, the piston continually repeats the four-stroke cycle.

TWO-CYCLE ENGINE

In the two-cycle engine, the entire series of strokes (intake, compression, power, and exhaust) takes place in two piston strokes.
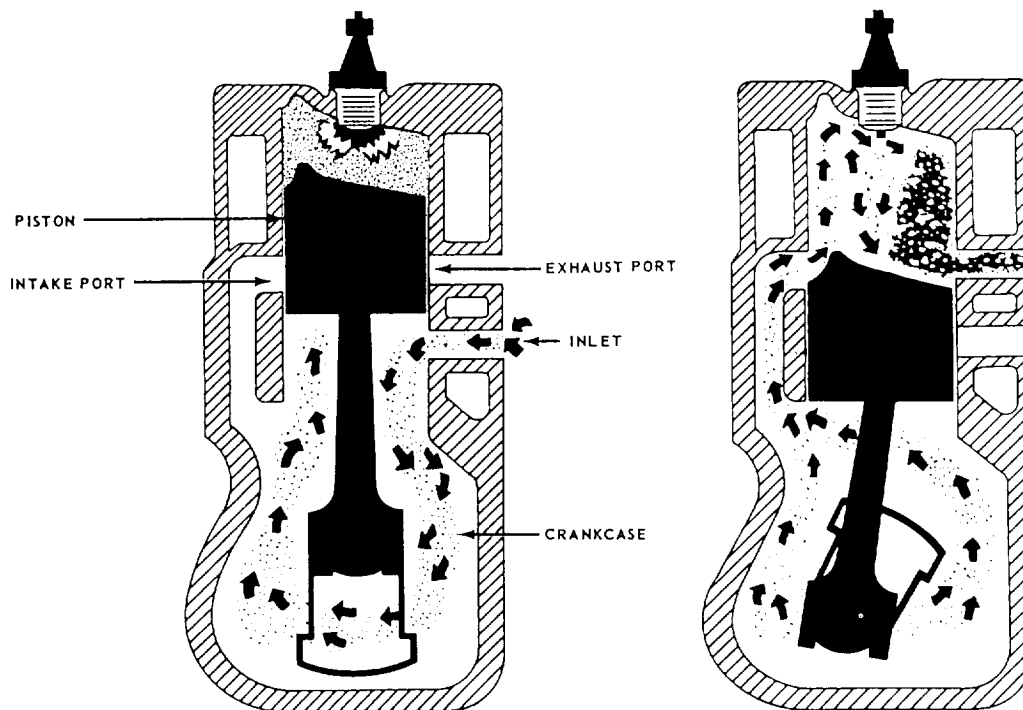
PISTON
INTAKE PORT
EXHAUST PORT
INLET
CRANKCASE

Figure 12-5.-Events in a two-cycle, internal combustion engine.

A two-cycle engine is shown in figure 12-5. Every other stroke in this engine is a power stroke. Each time the piston moves down, it is on the power stroke. Intake, compression, power, and exhaust still take place; but they are completed in just two strokes. Figure 12-5 shows that the intake and exhaust ports are cut into the cylinder wall instead of at the top of the combustion chamber as in the four-cycle engine. As the piston moves down on its power stroke, it first uncovers the exhaust port to let burned gases escape and then uncovers the intake port to allow a new fuel-air mixture to enter the combustion chamber. Then on the upward stroke, the piston covers both ports and, at the same time, compresses the new mixture in preparation for ignition and another power stroke.

In the engine shown in figure 12-5, the piston is shaped so that the incoming fuel-air mixture is directed upward, thereby sweeping out ahead of it the burned exhaust gases. Also, there is an inlet into the crankcase through which the fuel-air mixture passes before it enters the cylinder. This inlet is opened as the piston moves upward, but it is sealed as the piston moves downward on the power stroke. The downward moving piston slightly compresses the mixture in the crankcase. That gives the mixture enough pressure to pass rapidly through the intake port as the piston clears this port. This action improves the sweeping-out, or scavenging, effect of the mixture as it enters and clears the burned gases from the cylinder through the exhaust port.

FOUR-CYCLE VERSUS TWO-CYCLE ENGINES

You have probably noted that the two-cycle engine produces a power stroke every crankshaft revolution; the four-cycle engine requires two crankshaft revolutions for each power stroke. It might appear that the two-cycle engine could produce twice as much power as the four-cycle engine of the same size, operating at the same speed. However, that is not true. With the two-cycle engine, some of the power is used to drive the blower that forces the air-fuel charge into the cylinder under pressure. Also, the burned gases are not cleared from the cylinder. Additionally, because of the much shorter period the intake port is open (compared to the period the intake valve in a four-stroke-cycle is open), a smaller amount of fuel-air mixture is admitted. Hence, with less fuel-air mixture, less power per power stroke is produced compared to the power produced in a four-stroke cycle engine of like size operating at the same speed and under the same conditions. To increase the amount of fuel-air mixture, we use auxiliary devices with the two-stroke engine to ensure delivery of greater amounts of fuel-air mixture into the cylinder.
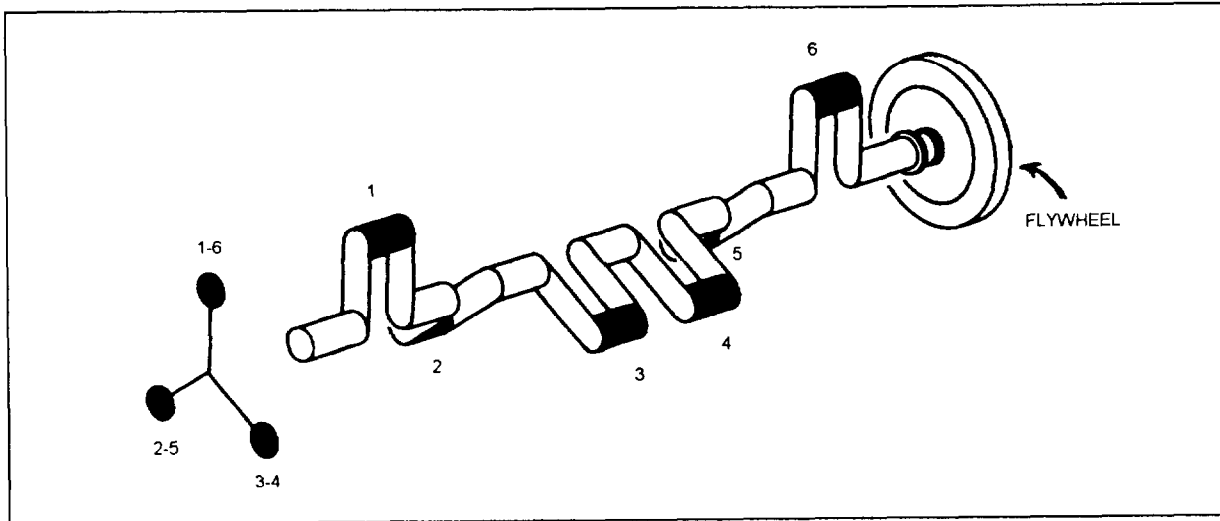
Figure 12-6.-Crankshaft for a six-cylinder engine.

MULTIPLE-CYLINDER ENGINES

The discussion so far in this chapter has concerned a single-cylinder engine. A single cylinder provides only one power impulse every two crankshaft revolutions in a four-cycle engine. It delivers power only one-fourth of the time. To provide for a more continuous flow of power, modem engines use four, six, eight, or more cylinders. The same series of cycles take place in each cylinder.

In a four-stroke cycle, six-cylinder engine, for example, the cranks on the crankshaft are set 120 degrees apart. The cranks for cylinders 1 and 6, 2 and 5, and 3 and 4 are in line with each other (fig. 12-6). The cylinders fire or deliver the power strokes in the following order: 1-5-3-6-2-4. Thus, the power strokes follow each other so closely that a continuous and even delivery of power goes to the crankshaft.

TIMING

In a gasoline engine, the valves must open and close at the proper times with regard to piston position and stroke. In addition, the ignition system must produce the sparks at the proper time so that the power strokes can start. Both valve and ignition system action must be properly timed if good engine performance is to be obtained.

Valve timing refers to the exact times in the engine cycle that the valves trap the mixture and then allow the burned gases to escape. The valves must open and close so that they are constantly in step with the piston movement of the cylinder they control. The position of the valves is determined by the camshaft; the position of the piston is determined by the crankshaft. Correct valve timing is obtained by providing the proper relationship between the camshaft and the crankshaft.

When the piston is at top dead center, the crankshaft can move 15° to 20° without causing the piston to move up and down any noticeable distance. This is one of the two rock positions (fig. 12-7) of the piston. When the piston moves up on the exhaust stroke, considerable momentum is given to the exhaust gases as they pass out through the exhaust valve port. If the exhaust valve closes at top dead center, a small amount of the gases
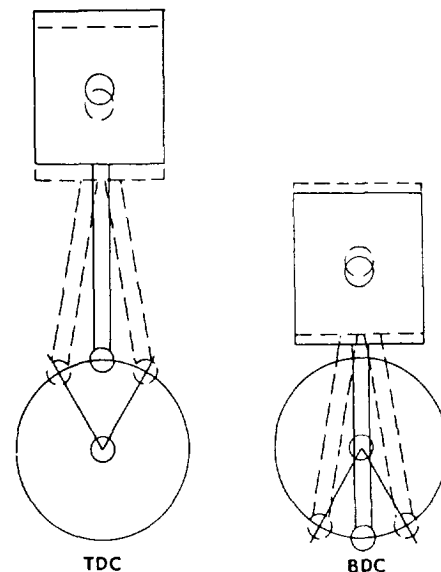

Figure 12-7.-Rock position.

will be trapped and will dilute the incoming fuel-air mixture when the intake valves open. Since the piston has little downward movement while in the rock position, the exhaust valve can remain open during this period and thereby permit a more complete scavenging of the exhaust gases.

Ignition timing refers to the timing of the sparks at the spark plug gap with relation to the piston position during the compression and power strokes. The ignition system is timed so that the sparks occurs before the piston reaches top dead center on the compression stroke. That gives the mixture enough time to ignite and start burning. If this time were not provided, that is, if the spark occurred at or after the piston reached top dead center, then the pressure increase would not keep pace with the piston movement.

At higher speeds, there is still less time for the fuel-air mixture to ignite and bum. To make up for this lack of time and thereby avoid power loss, the ignition system includes an advance mechanism that functions on speed.

CLASSIFICATION OF ENGINES

Engines for automotive and construction equipment may be classified in several ways: type of fuel used, type of cooling employed, or valve and cylinder arrangement. They all operate on the internal combustion principle. The application of basic principles of construction to particular needs or systems of manufacture has caused certain designs to be recognized as conventional.

The most common method of classification is based on the type of fuel used; that is, whether the engine burns gasoline or diesel fuel.

GASOLINE ENGINES VERSUS DIESEL ENGINES

Mechanically and in overall appearance, gasoline and diesel engines resemble one another. However, many parts of the diesel engine are designed to be somewhat heavier and stronger to withstand the higher temperatures and pressures the engine generates. The engines differ also in the fuel used, in the method of introducing it into the cylinders, and in how the air-fuel mixture is ignited. In the gasoline engine, we first mix air and fuel in the carburetor. After this mixture is compressed in the cylinders, it is ignited by an electrical spark from the spark plugs. The source of the energy producing the electrical spark may be a storage battery or a high-tension magneto.

The diesel engine has no carburetor. Air alone enters its cylinders, where it is compressed and reaches a high temperature because of compression. The heat of compression ignites the fuel injected into the cylinder and causes the fuel-air mixture to burn. The diesel engine needs no spark plugs; the very contact of the diesel fuel with the hot air in the cylinder causes ignition. In the gasoline engine the heat compression is not enough to ignite the air-fuel mixture; therefore, spark plugs are necessary.

ARRANGEMENT OF CYLINDERS

Engines are also classified according to the arrangement of the cylinders. One classification is the in-line, in which all cylinders are cast in a straight line above the crankshaft, as in most trucks. Another is the V-type, in which two banks of cylinders are mounted in a "V" shape above the crankshaft, as in many passenger vehicles. Another not-so-common arrangement is the horizontally opposed engine whose cylinders mount in two side rows, each opposite a central crankshaft. Buses often have this type of engine.

The cylinders are numbered. The cylinder nearest the front of an in-line engine is numbered 1. The others are numbered 2, 3,4, and so forth, from the front to rear. In V-type engines the numbering sequence varies with the manufacturer.

The firing order (which is different from the numbering order) of the cylinders is usually stamped on the cylinder block or on the manufacturer's nameplate.

VALVE ARRANGEMENT

The majority of internal combustion engines also are classified according to the position and arrangement of the intake and exhaust valves. This classification depends on whether the valves are in the cylinder block or in the cylinder head. Various arrangements have been used; the most common are the L-head, I-head, and F-head (fig. 12-8). The letter designation is used because the shape of the combustion chamber resembles the form of the letter identifying it.

L-Head

In the L-head engines, both valves are placed in the block on the same side of the cylinder. The valve-operating mechanism is located directly below the valves, and one camshaft actuates both the intake and exhaust valves.
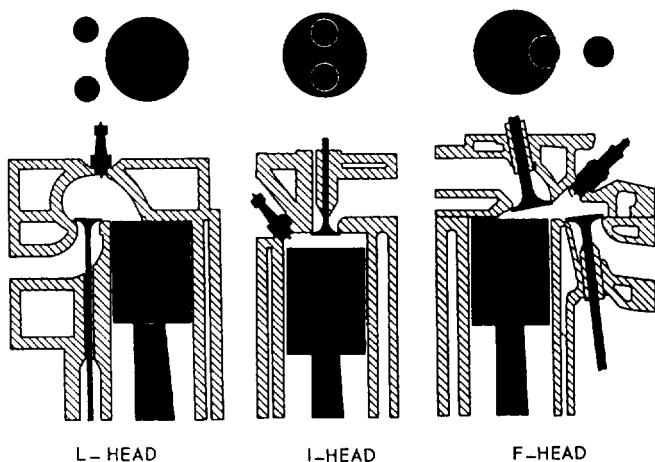
Figure 12-8.-L-, I-, and F-valve arrangement.

I-Head

Engines using the I-head construction are called valve-in-head or overhead valve engines, because the valves mount in a cylinder head above the cylinder. This arrangement requires a tappet, a push rod, and a rocker arm above the cylinder to reverse the direction of the valve movement. Only one camshaft is required for both valves. Some overhead valve engines make use of an overhead camshaft. This arrangement eliminates the long linkage between the camshaft and the valve.

F-Head

In the F-head engine, the intake valves normally are located in the head, while the exhaust valves are located in the engine block. This arrangement combines, in effect, the L-head and the I-head valve arrangements. The valves in the head are actuated from the camshaft through tappets, push rods, and rocker arms (I-head arrangement), while the valves in the block are actuated directly from the camshaft by tappets (L-head arrangement).

ENGINE CONSTRUCTION

Basic engine construction varies little, regardless of the size and design of the engine. The intended use of an engine must be considered before the design and size can be determined. The temperature at which an engine will operate has a great deal to do with the metals used in its construction.

The problem of obtaining servicing procedures and service parts in the field are simplified by the categorization of engines into families based on construction and design. Because many kinds of engines are needed for many different jobs, engines are designed to have closely related cylinder sizes, valve arrangements, and so forth. As an example, the General Motors series 71 engines may have two, three, four, or six cylinders. However, they are designed so that the same pistons, connecting rods, bearings, valves and valve operating mechanisms can be used in all four engines.

Engine construction, in this chapter, will be broken down into two categories: stationary parts and moving parts.

STATIONARY PARTS

The stationary parts of an engine include the cylinder block, cylinders, cylinder head or heads, crankcase, and the exhaust and intake manifolds. These parts furnish the framework of the engine. All movable parts are attached to or fitted into this framework.

Engine Cylinder Block

The engine cylinder block is the basic frame of a liquid-cooled engine, whether it is the in-line, horizontally opposed, or V-type. The cylinder block and crankcase are often cast in one piece that is the heaviest single piece of metal in the engine. (See fig. 12-9.) In small engines, where weight is an important consideration, the crankcase may be cast separately. In most large diesel engines, such as those used in power plants, the crankcase is cast separately and is attached to a heavy stationary engine base.

In practically all automotive and construction equipment, the cylinder block and crankcase are cast in one piece. In this course we are concerned primarily with liquid-cooled engines of this type.

The cylinders of a liquid-cooled engine are surrounded by jackets through which the cooling liquid circulates. These jackets are cast integrally with the cylinder block. Communicating passages permit the coolant to circulate around the cylinders and through the head.

The air-cooled engine cylinder differs from that of a liquid-cooled engine in that the cylinders are made individually, rather than cast in block. The cylinders of air-cooled engines have closely spaced fins surrounding the barrel; these fins provide an increased surface area from which heat can be dissipated. This engine design is in contrast to that of the liquid-cooled engine, which has a water jacket around its cylinders.
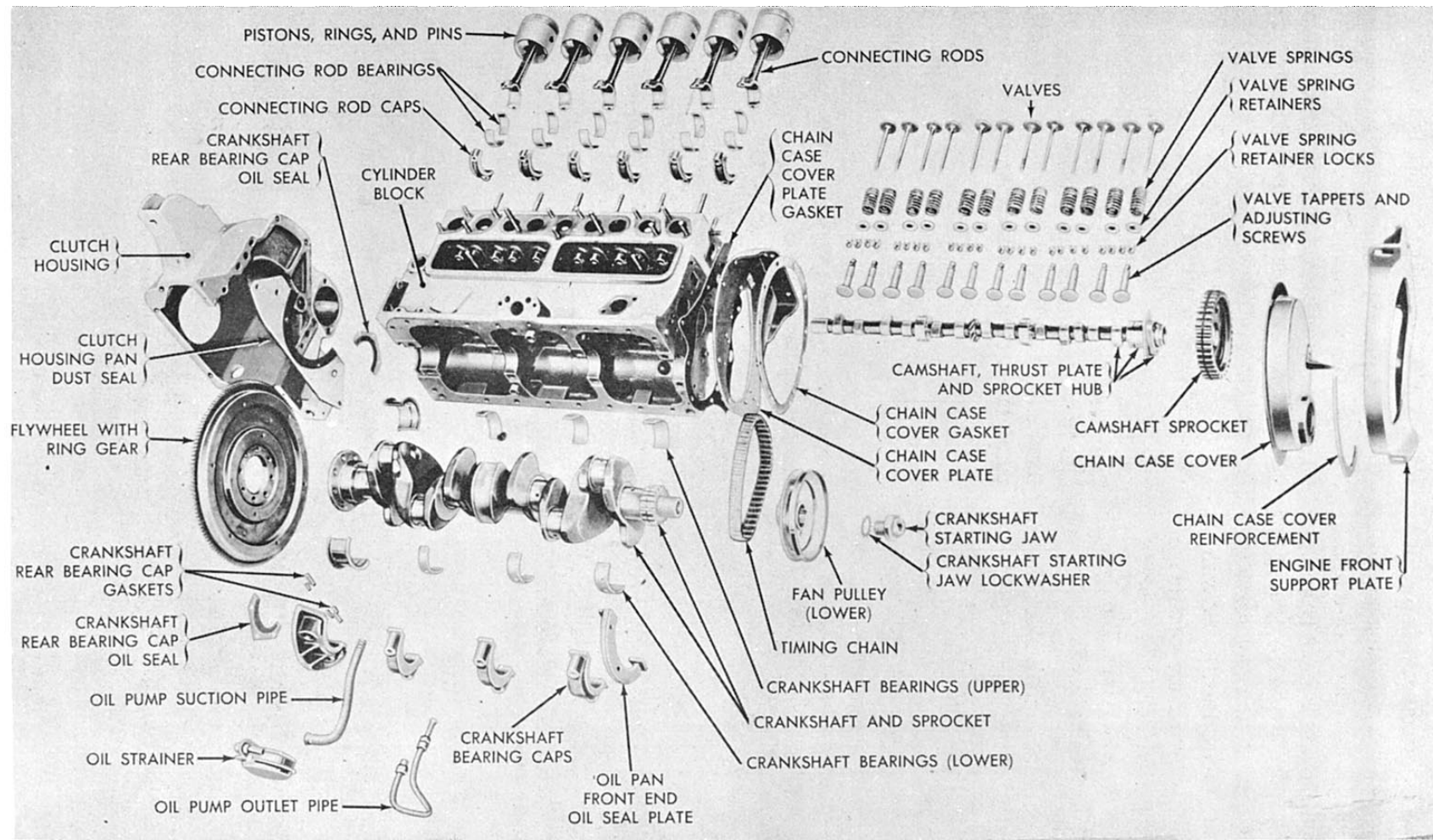
PISTONS, RINGS, AND PINS

CONNECTING ROD BEARINGS

CONNECTING ROD CAPS

CRANKSHAFT
REAR BEARING CAP
OIL SEAL

CYLINDER
BLOCK

CONNECTING RODS

VALVES

CHAIN
CASE
COVER
PLATE
GASKET

VALVE SPRINGS

VALVE SPRING
RETAINERS

VALVE SPRING
RETAINER LOCKS

VALVE TAPPETS AND
ADJUSTING
SCREWS

CLUTCH
HOUSING

CLUTCH
HOUSING PAN
DUST SEAL

FLYWHEEL WITH
RING GEAR

CRANKSHAFT
REAR BEARING CAP
GASKETS

CRANKSHAFT
REAR BEARING CAP
OIL SEAL

OIL PUMP SUCTION PIPE

OIL STRAINER

OIL PUMP OUTLET PIPE

CRANKSHAFT
BEARING CAPS

OIL PAN
FRONT END
OIL SEAL PLATE

CAMSHAFT, THRUST PLATE
AND SPROCKET HUB

CHAIN CASE
COVER GASKET

CHAIN CASE
COVER PLATE

FAN PULLEY
(LOWER)

TIMING CHAIN

CRANKSHAFT
STARTING JAW

CRANKSHAFT STARTING
JAW LOCKWASHER

CRANKSHAFT BEARINGS (UPPER)

CRANKSHAFT AND SPROCKET

CRANKSHAFT BEARINGS (LOWER)

CAMSHAFT SPROCKET

CHAIN CASE COVER

CHAIN CASE COVER
REINFORCEMENT

ENGINE FRONT
SUPPORT PLATE

Figure 12-9.—Cylinder block and components.

Cylinder Block Construction

The cylinder block is cast from gray iron or iron alloyed with other metals such as nickel, chromium, or molybdenum. Some lightweight engine blocks are made from aluminum.

Cylinders are machined by grinding or boring to give them the desired true inner surface. During normal engine operation, cylinder walls will wear out-of-round, or they may become cracked and scored if not properly lubricated or cooled. Liners (sleeves) made of metal alloys resistant to wear are used in many gasoline engines and practically all diesel engines to lessen wear. After they have been worn beyond the maximum oversize, the liners can be replaced individually, which permits the use of standard pistons and rings. Thus, you can avoid replacing the entire cylinder block

The liners are inserted into a hole in the block with either a PRESS FIT or a SLIP FIT. Liners are further designated as either a WET-TYPE or DRY-TYPE. The wet-type liner comes in direct contact with the coolant and is sealed at the top by a metallic sealing ring and at the bottom by a rubber sealing ring. The dry-type liner does not contact the coolant.

Engine blocks for L-head engines contain the passageways for the valves and valve ports. The lower part of the block (crankcase) supports the crankshaft (the main bearings and bearing caps) and provides a place to which the oil pan can be fastened.

The camshaft is supported in the cylinder block by bushings that fit into machined holes in the block. On L-head in-line engines, the intake and exhaust manifolds are attached to the side of the cylinder block. On L-head V-8 engines, the intake manifold is located between the two banks of cylinders; these engines have two exhaust manifolds, one on the outside of each bank.

Cylinder Head

The cylinder head provides the combustion chambers for the engine cylinders. It is built to conform to the arrangement of the valves: L-head, I-head, or other.

In the water-cooled engine, the cylinder head (fig. 12-10) is bolted to the top of the cylinder block to close the upper end of the cylinders. It contains passages,
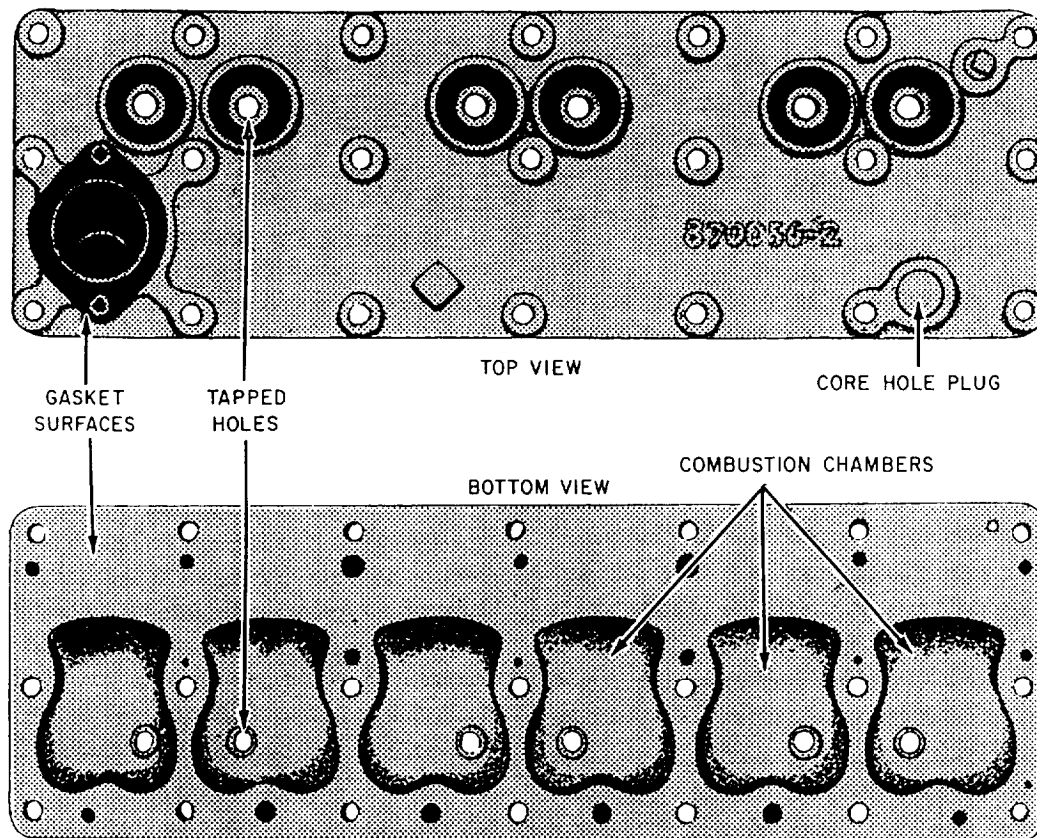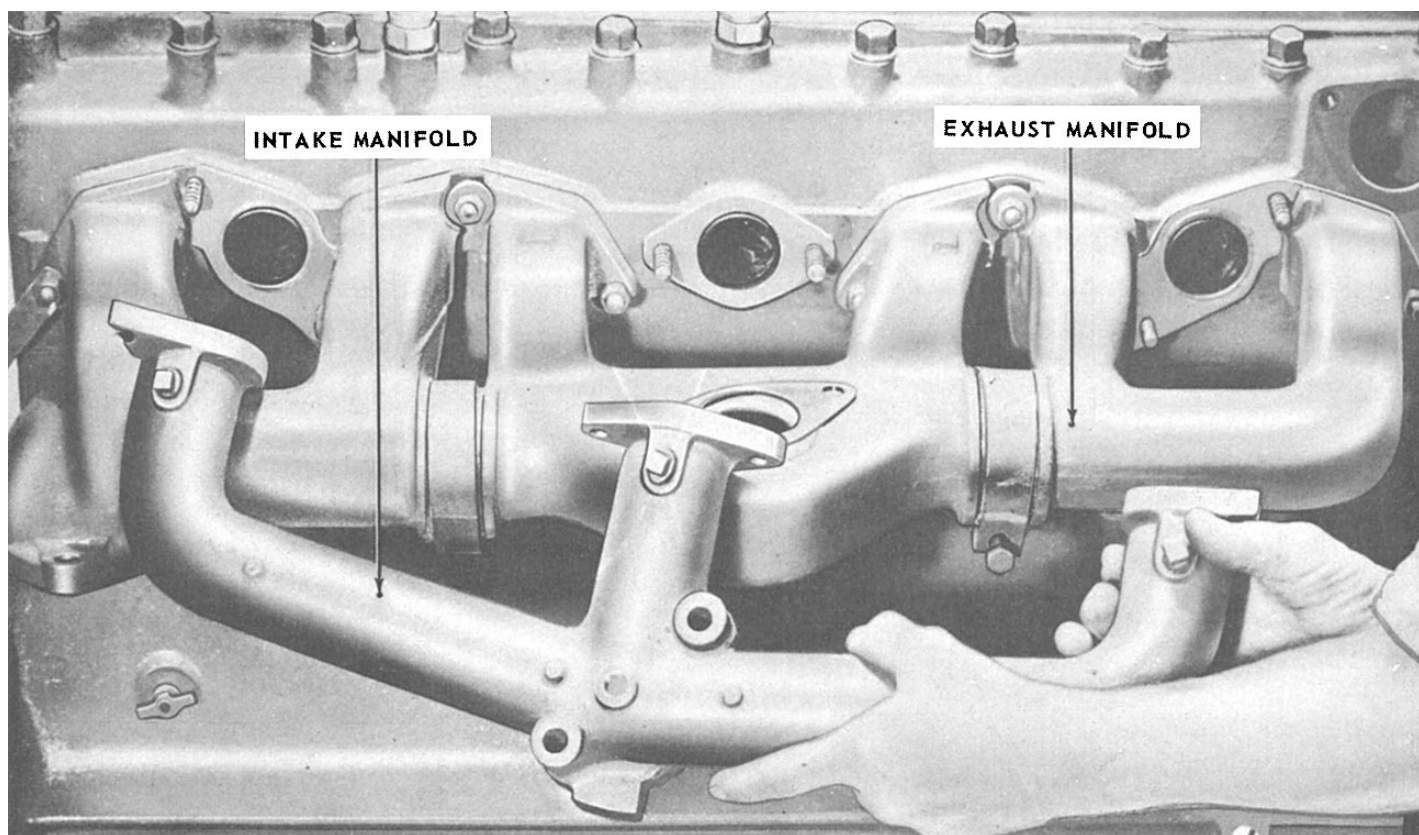

Figure 12-10-Cylinder head for L-head engine.

Figure 12-11.—Intake and exhaust manifolds.

matching those of the cylinder block, that allow the cooling water to circulate in the head. The head also helps keep compression in the cylinders. The gasoline engine contains tapped holes in the cylinder head that lead into the combustion chamber. The spark plugs are inserted into these tapped holes.

In the diesel engine the cylinder head may be cast in a single unit, or it may be cast for a single cylinder or two or more cylinders. Separated head sections (usually covering one, two, or three cylinders in large engines) are easy to handle and can be removed.

The L-head type of cylinder head shown in figure 12-10 is a comparatively simple casting. It contains water jackets for cooling, openings for spark plugs, and pockets into which the valves operate. Each pocket serves as a part of the combustion chamber. The fuel-air mixture is compressed in the pocket as the piston reaches the end of the compression stroke. Note that the pockets have a rather complex curved surface. This shape has been carefully designed so that the fuel-air mixture, compressed, will be subjected to violent turbulence. This turbulence ensures uniform mixing of the fuel and air, thus improving the combustion process.

The I-head (overhead-valve) type of cylinder head contains not only valve and combustion chamber pockets and water jackets for cooling spark-plug openings, but it also contains and supports the valves and valve-operating mechanisms. In this type of cylinder head, the water jackets must be large enough to cool not only the top of the combustion chamber but also the valve seats, valves, and valve-operating mechanisms.

Crankcase

The crankcase is that part of the engine block below the cylinders. It supports and encloses the crankshaft and provides a reservoir for the lubricating oil. Often times the crankcase contains a place for mounting the oil pump, oil filter, starting motor, and generator. The lower part of the crankcase is the OIL PAN, which is bolted at the bottom. The oil pan is made of pressed or cast steel and holds from 4 to 9 quarts of oil, depending on the engine design.

The crankcase also has mounting brackets that support the entire engine on the vehicle frame. These brackets are either an integral part of the crankcase or

are bolted to it so that they support the engine at three or four points. These points of contact usually are cushioned with rubber that insulates the frame and the body of the vehicle from engine vibration and therefore prevents damage to the engine supports and the transmission.

Exhaust Manifold

The exhaust manifold is a tube that carries waste products of combustion from the cylinders. On L-head engines the exhaust manifold is bolted to the side of the engine block on; overhead-valve engines it is bolted to the side of the engine cylinder head. Exhaust manifolds may be single iron castings or may be cast in sections. They have a smooth interior surface with no abrupt change in size (see fig. 12-1 1).

Intake Manifold

The intake manifold on a gasoline engine carries the fuel-air mixture from the carburetor and distributes it as evenly as possible to the cylinders. On a diesel engine, the manifold carries only air to the cylinders. The intake manifold is attached to the block on L-head engines and to the side of the cylinder head on overhead-valve engines. (See fig. 12-11.)

In gasoline engines, smooth and efficient engine performance depends largely on whether the fuel-air mixtures that enter each cylinder are uniform in strength, quality, and degree of vaporization. The inside walls of the manifold must be smooth to offer little obstruction to the flow of the fuel-air mixture. The manifold is designed to prevent the collecting of fuel at the bends in the manifold.

The intake manifold should be as short and straight as possible to reduce the chances of condensation between the carburetor and cylinders. Some intake manifolds are designed so that hot exhaust gases heat their surfaces to help vaporize the fuel.

Gaskets

The principal stationary parts of an engine have just been explained. The gaskets (fig. 12- 12) that serve as seals between these parts require as much attention during engine assembly as any other part. It is impractical to machine all surfaces so that they fit together to form a perfect seal. The gaskets make a joint that is air, water, or oil tight. Therefore, when properly
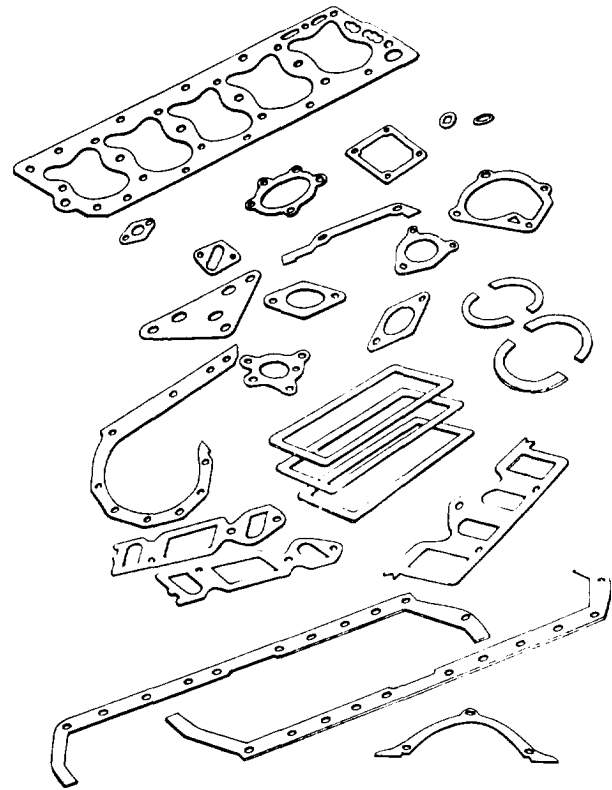

Figure 12-12.-Engine overhaul gasket kit.

installed, they prevent loss of compression, coolant, or lubricant.

MOVING PARTS OF AN ENGINE

The moving parts of an engine serve an important function in turning heat energy into mechanical energy. They further convert reciprocal motion into rotary motion. The principal moving parts are the piston assembly, connecting rods, crankshaft assembly (includes flywheel and vibration dampener), camshaft, valves, and gear train.

The burning of the fuel-air mixture within the cylinder exerts a pressure on the piston, thus pushing it down in the cylinder. The action of the connecting rod and crankshaft converts this downward motion to a rotary motion.

Piston Assembly

Engine pistons serve several purposes. They transmit the force of combustion to the crankshaft through the connecting rod. They act as a guide for the upper end of the connecting rod. And they also serve as
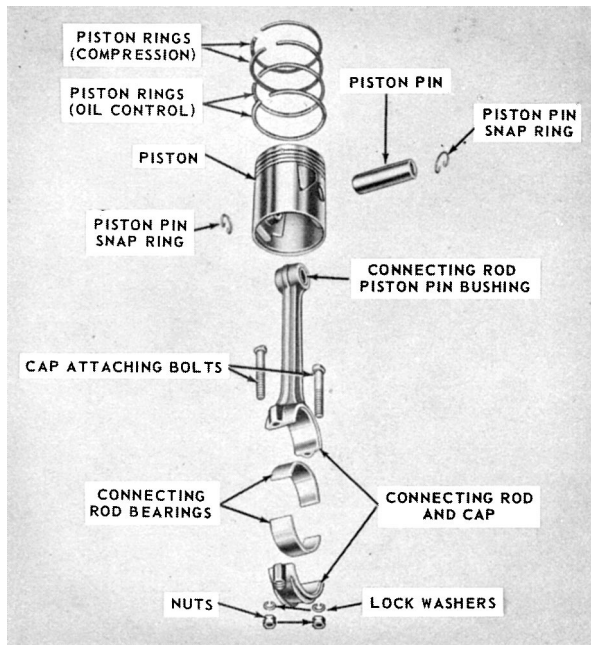
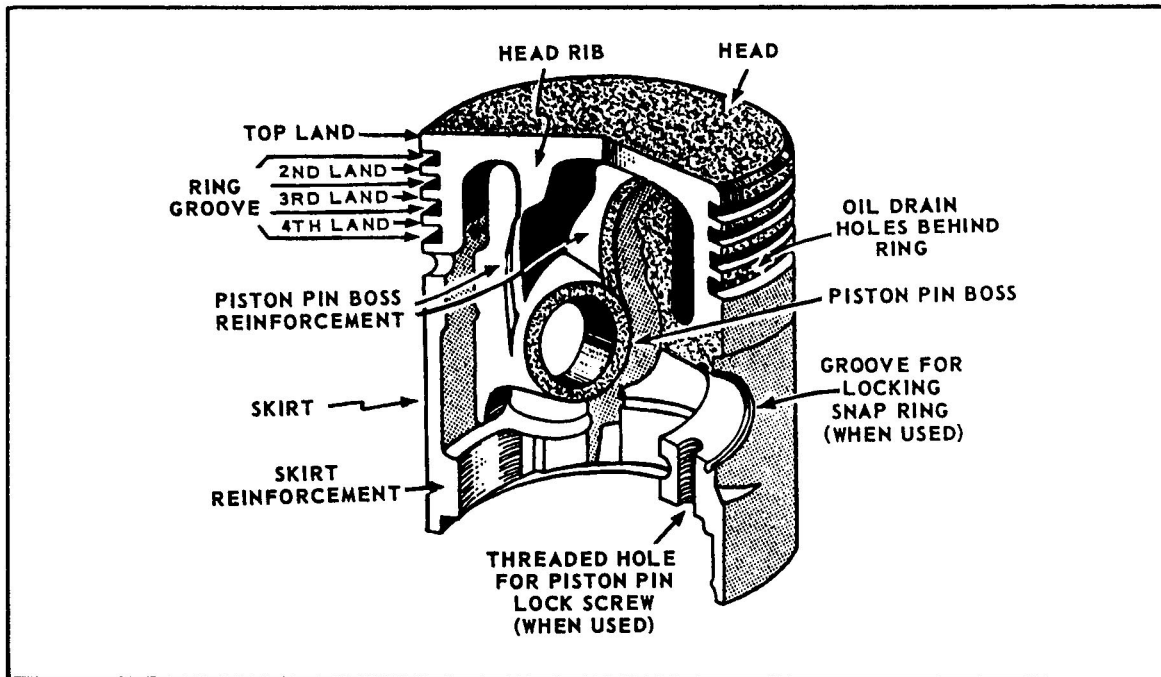**Figure 12-13.—Piston and connecting rod (exploded view).**

a carrier for the piston rings used to seal the compression in the cylinder. (See. fig. 12-13.)

The piston must come to a complete stop at the end of each stroke before reversing its course in the cylinder. To withstand this rugged treatment and wear, it must be made of tough material, yet be light in weight. To overcome inertia and momentum at high speed, it must be carefully balanced and weighed. All the pistons used in any one engine must be of similar weight to avoid excessive vibration. Ribs are used on the underside of the piston to reinforce the hand. The ribs also help to conduct heat from the head of the piston to the piston rings and out through the cylinder walls.
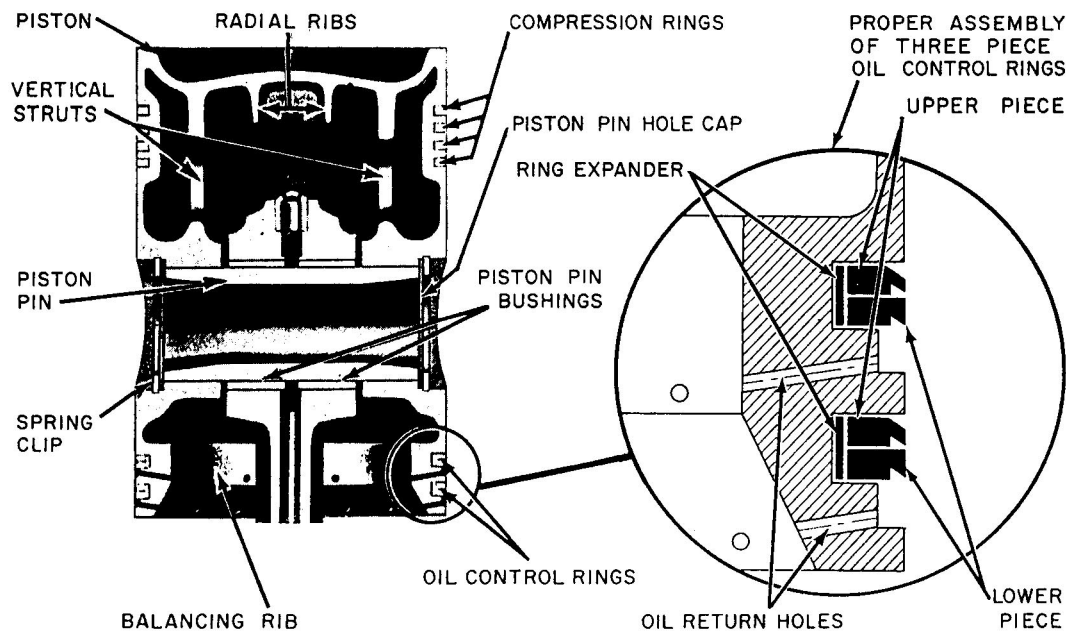
The structural components of the piston are the head, skirt, ring grooves, and land (fig. 12-14). However, all pistons do not look like the typical one illustrated here. Some have differently shaped heads. Diesel engine pistons usually have more ring grooves and rings than gasoline engine pistons. Some of these rings may be installed below as well as above the wrist or piston pin (fig. 12-15).

Fitting pistons properly is important. Because metal expands when heated and space must be provided for lubricants between the pistons and the cylinder walls, the pistons are fitted to the engine with a specified clearance. This clearance depends upon the size or diameter of the piston and the material form which it is made. Cast iron does not expand as fast or as much as aluminum. Aluminum pistons require more clearance to prevent binding or seizing when the engine gets hot. The skirt of bottom part of the piston runs much cooler than the top; therefore, it does not require as much clearance as the head.
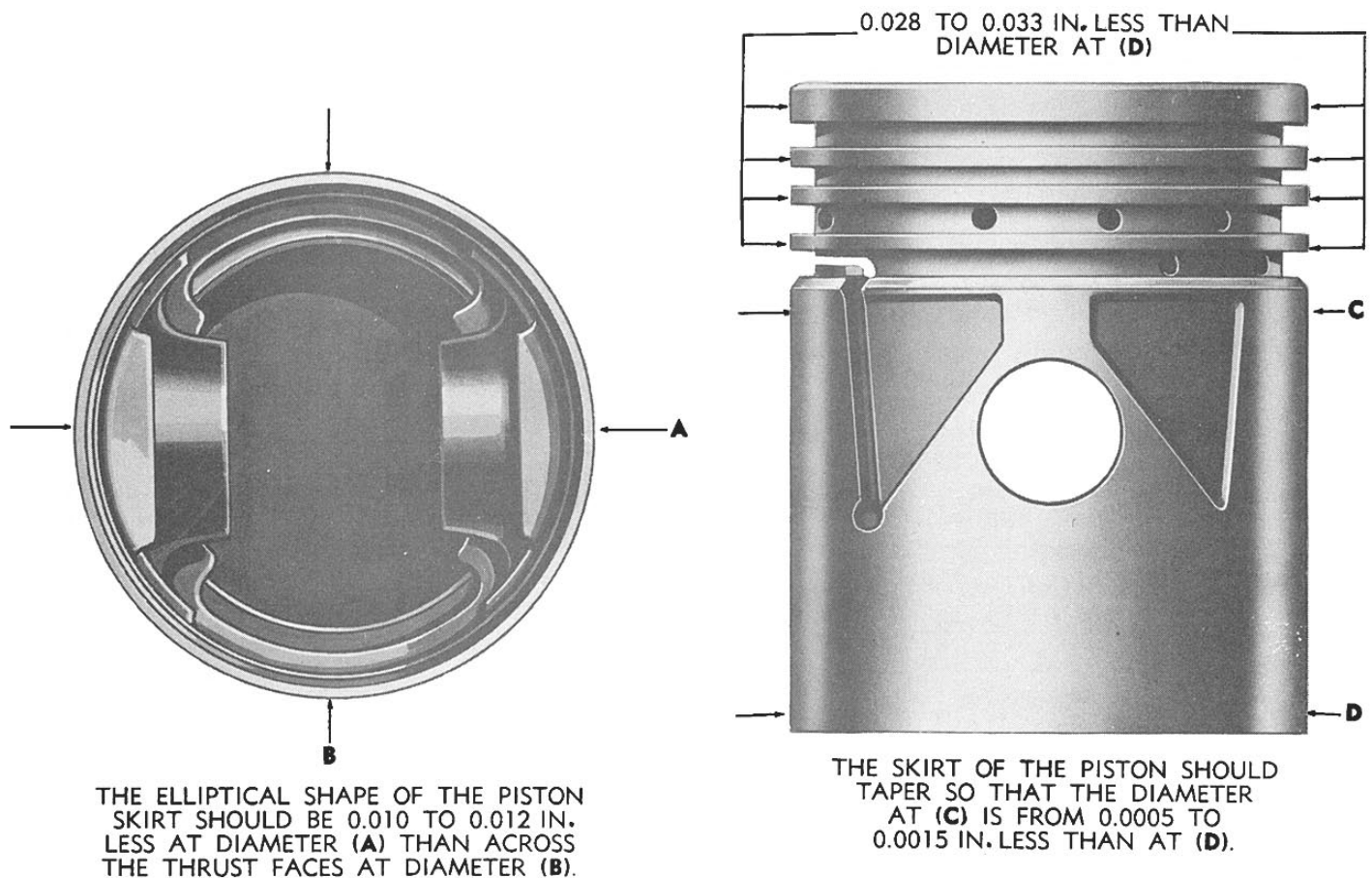

Figure 12-14.—The parts of a piston.

12-14

Figure 12-15.—Piston assembly.

THE ELLIPTICAL SHAPE OF THE PISTON SKIRT SHOULD BE 0.010 TO 0.012 IN. LESS AT DIAMETER (A) THAN ACROSS THE THRUST FACES AT DIAMETER (B).

THE SKIRT OF THE PISTON SHOULD TAPER SO THAT THE DIAMETER AT (C) IS FROM 0.0005 TO 0.0015 IN. LESS THAN AT (D).

Figure 12-16.—Cam-ground piston.

The piston is kept in alignment by the skirt, which is usually cam ground (elliptical in cross section) (fig.12-16). This elliptical shape permits the piston to fit the cylinder, regardless of whether the piston is cold or at operating temperature. The narrowest diameter of the piston is at the piston pin bosses, where the piston skirt is thickest. At the widest diameter of the piston, the piston skirt is thinnest. The piston is fitted to close limits at its widest diameter so that the piston noise (slap) is prevented during the engine warm-up. As the piston is

12-15
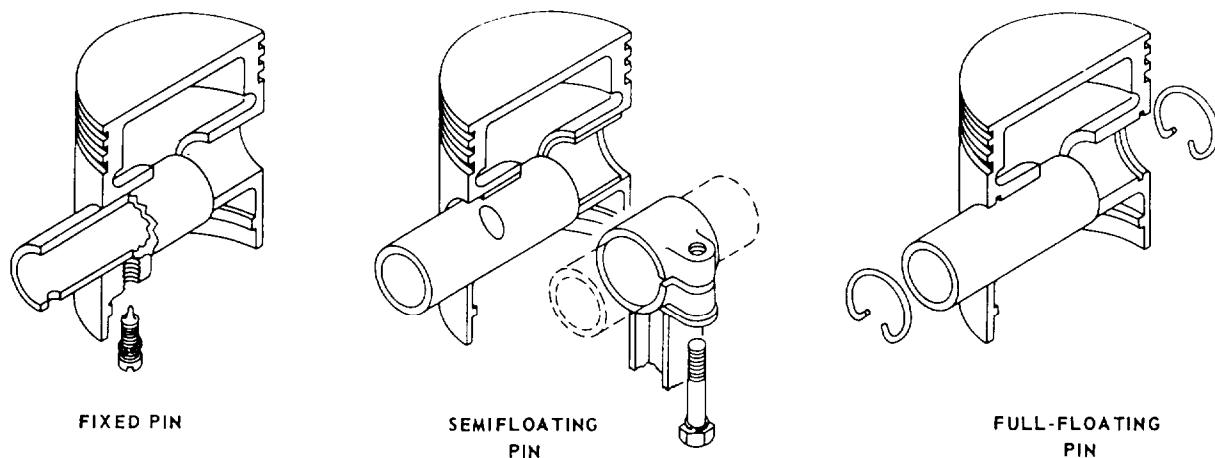
FIXED PIN   SEMIFLOATING PIN   FULL-FLOATING PIN

Figure 12-17.-Piston pin types.

expanded by the heat generated during operation, it becomes round because the expansion is proportional to the temperature of the metal. The walls of the skirt are cut away as much as possible to reduce weight and to prevent excessive expansion during engine operation. Many aluminum pistons are made with split skirts so that when the pistons expand, the skirt diameter will not increase.

The two types of piston skirts found in most engines are the full trunk and the slipper. The full-trunk-type skirt, more widely used, has a full cylindrical shape with bearing surfaces parallel to those of the cylinder, giving more strength and better control of the oil film. The slipper-type (cutaway) skirt has considerable relief on the sides of the skirt, leaving less area for possible contact with the cylinder walls and thereby reducing friction.

PISTON PINS.— The piston is attached to the connecting rod by the piston pin (wrist pin). The pin passes through the piston pin bosses and through the upper end of the connecting rod, which rides within the piston on the middle of the pin. Piston pins are made of alloy steel with a precision finish and are case hardened and sometimes chromium plated to increase their wearing qualities. Their tubular construction gives them maximum strength with minimum weight. They are lubricated by splash from the crankcase or by pressure through passages bored in the connecting rods.

Three methods are commonly used for fastening a piston pin to the piston and the connecting rod: fixed pin, semifloating pin, and full-floating pin (fig. 12-17). The anchored, or fixed, pin attaches to the piston by a screw running through one of the bosses; the connecting rod oscillates on the pin. The semifloating pin is

anchored to the connecting rod and turns in the piston pin bosses. The full-floating pin is free to rotate in the connecting rod and in the bosses, while plugs or snap-ring locks prevent it from working out against the sides of the cylinder.

PISTON RINGS.— Piston rings are used on pistons to maintain gastight seals between the pistons and cylinders, to aid in cooling the piston, and to control cylinder-wall lubrication. About one-third of the heat absorbed by the piston passes through the rings to the cylinder wall. Piston rings are often complicated in design, are heat treated in various ways, and are plated with other metals. Piston rings are of two distinct classifications: compression rings and oil control rings. (See fig. 12-18.)

The principal function of a compression ring is to prevent gases from leaking by the piston during the compression and power strokes. All piston rings are split to permit assembly to the piston and to allow for expansion. When the ring is in place, the ends of the split joint do not form a perfect seal; therefore, more than one ring must be used, and the joints must be staggered around the piston. If cylinders are worn, expanders (figs. 12-15 and 12-18) are sometimes used to ensure a perfect seal.

The bottom ring, usually located just above the piston pin, is an oil-regulating ring. This ring scrapes the excess oil from the cylinder walls and returns some of it, through slots, to the piston ring grooves. The ring groove under an oil ring has openings through which the oil flows back into the crankcase. In some engines, additional oil rings are used in the piston skirt below the piston pin.
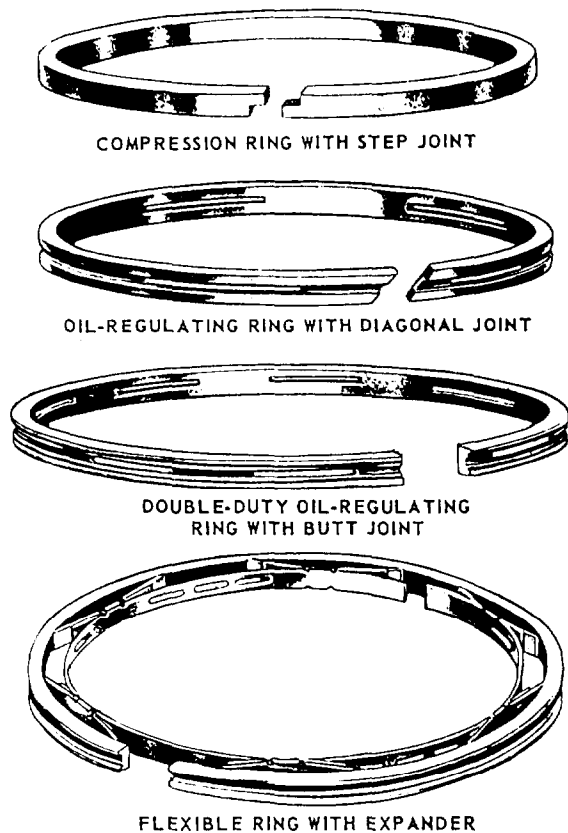
12-16

COMPRESSION RING WITH STEP JOINT

OIL-REGULATING RING WITH DIAGONAL JOINT

DOUBLE-DUTY OIL-REGULATING
RING WITH BUTT JOINT

FLEXIBLE RING WITH EXPANDER

Figure 12-18.-Piston rings.

FLYWHEEL (WITH STARTER GEAR)

COUNTERWEIGHTS

TIMING GEAR

MAIN (SUPPORT) BEARING JOURNALS

CONNECTING ROD BEARING JOURNALS

Figure 12-19.-Crankshaft of a four-cylinder engine.

Connecting Rods

Connecting rods must be light and yet strong enough to transmit the thrust of the pistons to the crankshaft. Connecting rods are drop forged from a steel alloy capable of withstanding heavy loads without bending or twisting. Holes at the upper and lower ends are machined to permit accurate fitting of bearings. These holes must be parallel.

The upper end of the connecting rod is connected to the piston by the piston pin. If the piston pin is locked in the piston pin bosses or if it floats in both the piston and the connecting rod, the upper hold of the connecting rod will have a solid bearing (bushing) of bronze or similar material. As the lower end of the connecting rod revolves with the crankshaft, the upper end is forced to turn back and forth on the piston pin. Although this movement is slight, the bushing is necessary because of the high pressure and temperatures. If the piston pin is semifloating, a bushing is not needed.
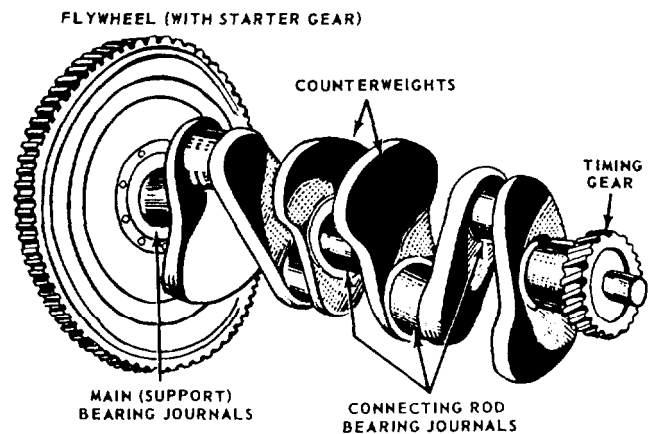
The lower hole in the connecting rod is split to permit it to be clamped around the crankshaft. The bottom part, or cap, is made of the same material as the rod and is attached by two or more bolts. The surface that bears on the crankshaft is generally a bearing material in the form of a separate split shell; in a few cases, it may be spun or die-cast in the inside of the rod and cap during manufacture. The two parts of the separate bearing are positioned in the rod and cap by dowel pins, projections, or short brass screws. Split bearings may be of the precision or semiprecision type.

The precision type bearing is accurately finished to fit the crankpin and does not require further fitting during installation. It is positioned by projections on the shell that match reliefs in the rod and cap. The projections prevent the bearings from moving sideways and prevent rotary motion in the rod and cap.

The semiprecision-type bearing is usually fastened to or die-cast with the rod and cap. Before installation, it is machined and fitted to the proper inside diameter with the cap and rod bolted together.

Crankshaft

As the pistons collectively might be regarded as the heart of the engine, so the crankshaft might be considered the backbone (fig. 12-19). It ties together the reactions of the pistons and the connecting rods, transforming their reciprocating motion into rotary motion. It transmits engine power through the flywheel, clutch, transmission, and differential to drive your vehicle.

The crankshaft is forged or cast from an alloy of steel and nickel. It is machined smooth to provide
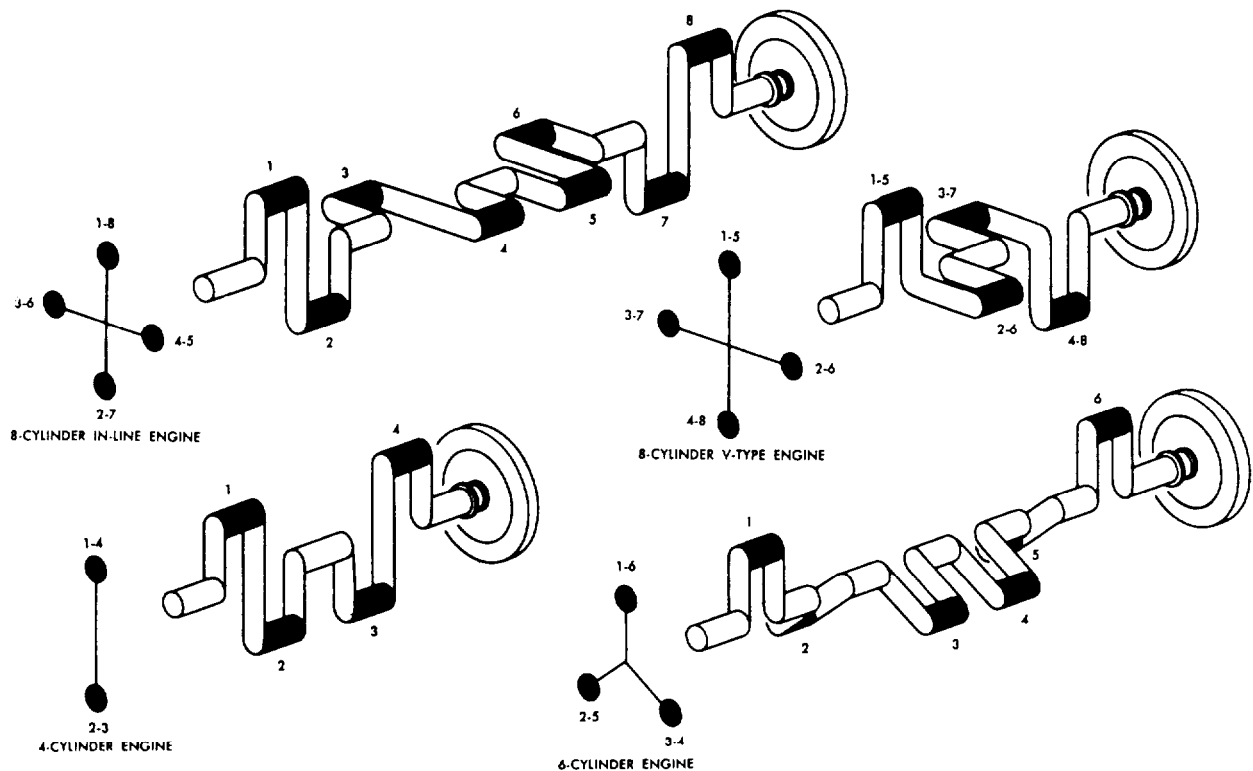
Figure 12-20.-Crankshaft and throw arrangements commonly used.

bearing surfaces for the connecting rods and the main bearings. It is case-hardened (coated in a furnace with copper alloyed and carbon). These bearing surfaces are called journals. The crankshaft counterweights impede the centrifugal force of the connecting rod and assembly attached to the throws or points of bearing support. These throws must be placed so that they counter-balance each other.
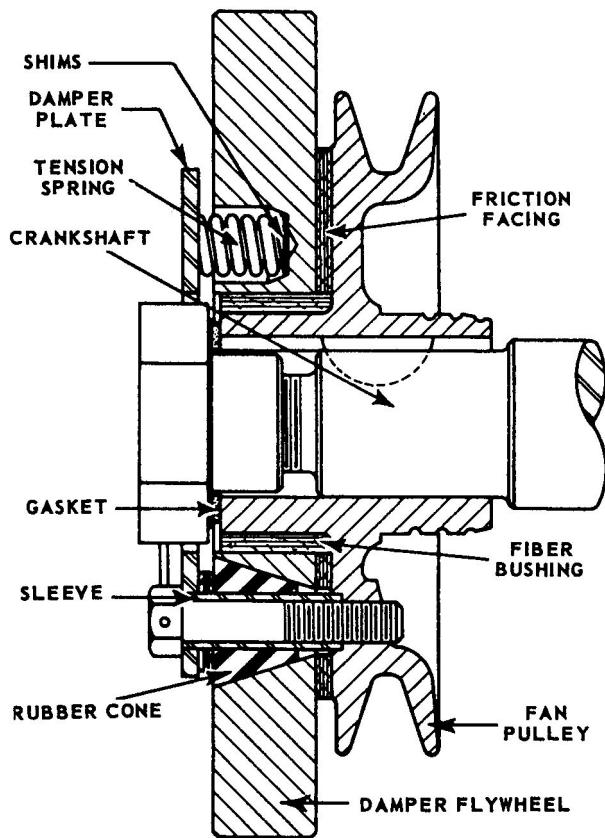
Crankshaft and throw arrangements for four-, six-, and eight-cylinder engines are shown in figure 12-20. Four-cylinder engine crankshafts have either three or five main support bearings and four throws in one plane. As shown in the figure, the four throws for the number 1 and 4 cylinders (four-cylinder engine) are 180° from those for the number 2 and 3 cylinders. On six-cylinder engine crankshafts, each of the three pairs of throws is arranged 120° from the other two. Such crankshafts may be supported by as many as seven main bearings—one at each end of the shaft and one between each pair of crankshaft throws. The crankshafts of eight-cylinder V-type engines are similar to those of the four-cylinder in-line type. They may have each of the four throws fixed at 90° from each other (as in fig. 12-20) for better balance and smoother operation.

V-type engines usually have two connecting rods fastened side by side on one crankshaft throw. With this arrangement, one bank of the engine cylinders is set slightly ahead of the other to allow the two rods to clear each other.

Vibration Damper

The power impulses of an engine result in torsional vibration in the crankshaft. A vibration damper mounted on the front of the crankshaft controls this vibration (fig. 12-21). If this torsional vibration were not controlled, the crankshaft might actually break at certain speeds.

Most types of vibration dampers resemble a miniature clutch. A friction facing is mounted between the hub face and a small damper flywheel. The damper flywheel is mounted on the hub face with bolts that go through rubber cones in the flywheel. These cones permit limited circumferential movement between the crankshaft and damper flywheel. That reduces the effects of the torsional vibration in the crankshaft. Several other types of vibration dampers are used; however, they all operate in essentially the same way.
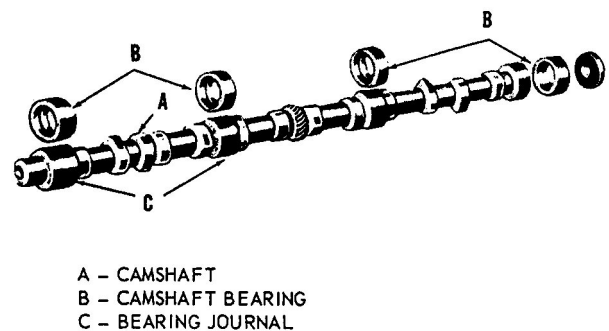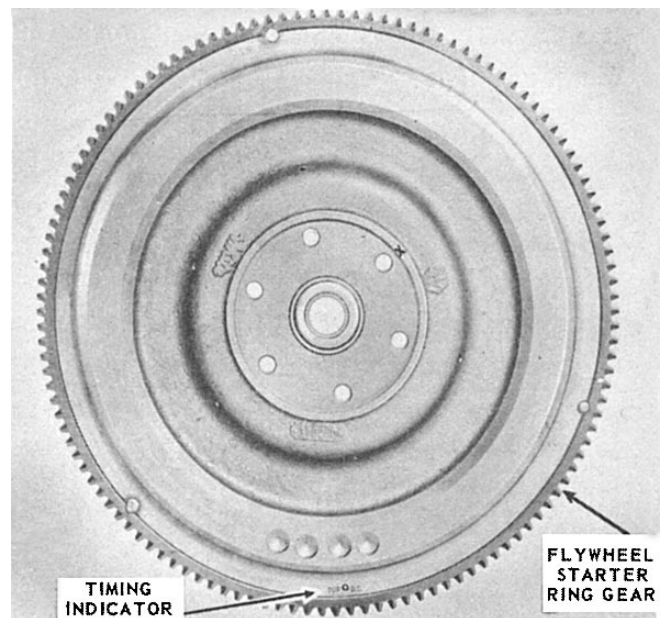
Figure 12-21.-Sectional view of a typical vibration damper.

A – CAMSHAFT
B – CAMSHAFT BEARING
C – BEARING JOURNAL

Figure 12-23.-Camshaft and bushings.

Engine Flywheel

The flywheel mounts at the rear of the crankshaft near the rear main bearing. This is usually the longest and heaviest main bearing in the engine, as it must support the weight of the flywheel.

The flywheel (fig. 12-22) stores up rotation energy during the power impulses of the engine. It releases this energy between power impulses, thus assuring less fluctuation in engine speed and smoother engine operation. The size of the flywheel will vary with the number of cylinders and the general construction of the engine. With the large number of cylinders and the consequent overlapping of power impulses, there is less need for a flywheel; consequently, the flywheel can be relatively small. The flywheel rim carries a ring gear, either integral with or shrunk on the flywheel, that meshes with the starter driving gear for cranking the engine. The rear face of the flywheel is usually machined and ground and acts as one of the pressure surfaces for the clutch, becoming a part of the clutch assembly.

Valves and Valve Mechanisms

Most engines have two valves for each cylinder, one intake and one exhaust valve. Since each of these valves operates at different times, separate operating mechanisms must be provided for each valve. Valves are normally held closed by heavy springs and by compression in the combustion chamber. The purpose of the valve-actuating mechanism is to overcome the spring pressure and open the valves at the proper time. The valve-actuating mechanism includes the engine camshaft, camshaft followers (tappets), pushrods, and rocker arms.

CAMSHAFT.—The camshaft (fig. 12-23) is enclosed in the engine block. It has eccentric lobes (cams) ground on it for each valve in the engine. As the
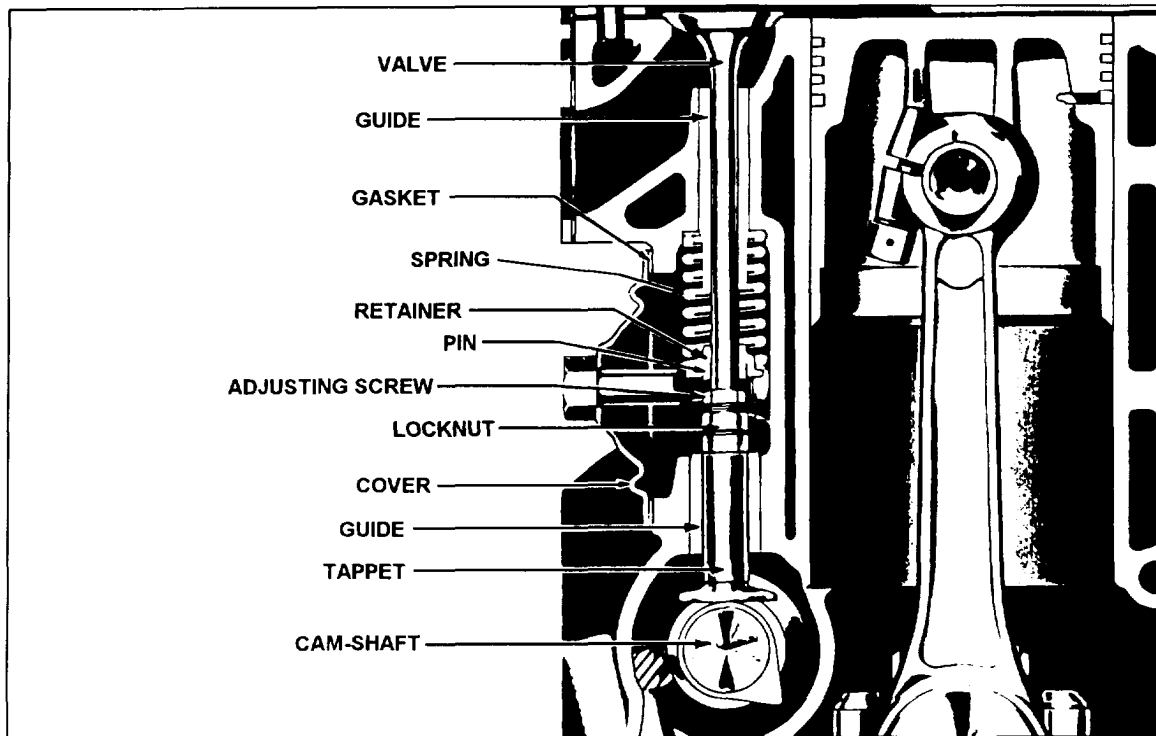
Figure 12-24.-L-head valve operating mechanism.

camshaft rotates, the cam lobe moves up under the valve tappet, exerting an upward thrust through the tappet against the valve stem or a pushrod. This thrust overcomes the valve spring pressure as well as the gas pressure in the cylinder, causing the valve to open. When the lobe moves from under the tappet, the valve spring pressure reseats the valve.

On L-, F-, or I-head engines, the camshaft is usually located to one side and above the crankshaft; in V-type engines, it is usually located directly above the crankshaft. On the overhead camshaft engine, such as the Murphy diesel, the camshaft is located above the cylinder head.

The camshaft of a four-stroke cycle engine turns at one-half engine speed. It is driven off the crankshaft through timing gears or a timing chain. In the two-stroke cycle engine, the camshaft must turn at the same speed as the crankshaft so that each valve may open and close once in each revolution of the engine.

In most cases the camshaft will do more than operate the valve mechanism. It may have extra cams or gears that operate fuel pumps, fuel injectors, the ignition distributor, or the lubrication pump.

Camshafts are supported in the engine block by journals in bearings. Camshaft bearing journals are the hugest machined surfaces on the shaft. The bearings are usually made of bronze and are bushings rather than split bearings. The bushings are lubricated by oil circulating through drilled passages from the crankcase. The stresses on the camshaft are small; therefore, the bushings are not adjustable and require little attention. The camshaft bushings are replaced only when the engine requires a complete overhaul.

FOLLOWERS.— Camshaft followers are the parts of the valve-actuating mechanism (figs. 12-24 and 12-25) that contact the camshaft. You will probably hear them called valve tappets or vale lifters. In the L-head engine, the followers directly contact the end of the valve stem and have an adjusting device in them. In the overhead valve engine, the followers contact the pushrod that operates the rocker arm. The end of the rocker arm opposite the pushrod contacts the valve stem. The valve adjusting device, in this case, is in the rocker arm.

Many engines have self-adjusting, hydraulic valve lifters that always operate at zero clearance.
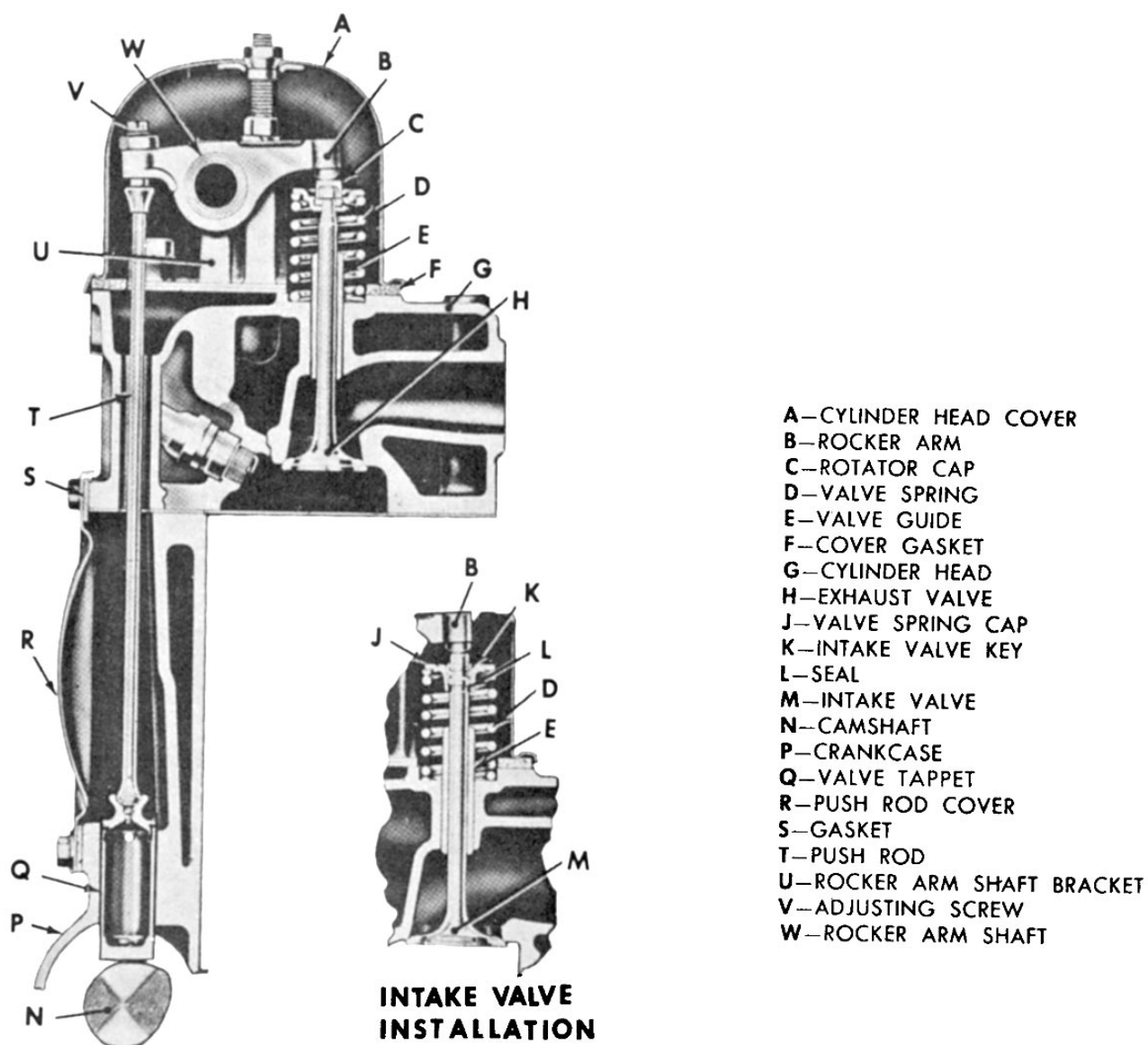
A—CYLINDER HEAD COVER
B—ROCKER ARM
C—ROTATOR CAP
D—VALVE SPRING
E—VALVE GUIDE
F—COVER GASKET
G—CYLINDER HEAD
H—EXHAUST VALVE
J—VALVE SPRING CAP
K—INTAKE VALVE KEY
L—SEAL
M—INTAKE VALVE
N—CAMSHAFT
P—CRANKCASE
Q—VALVE TAPPET
R—PUSH ROD COVER
S—GASKET
T—PUSH ROD
U—ROCKER ARM SHAFT BRACKET
V—ADJUSTING SCREW
W—ROCKER ARM SHAFT

INTAKE VALVE
INSTALLATION

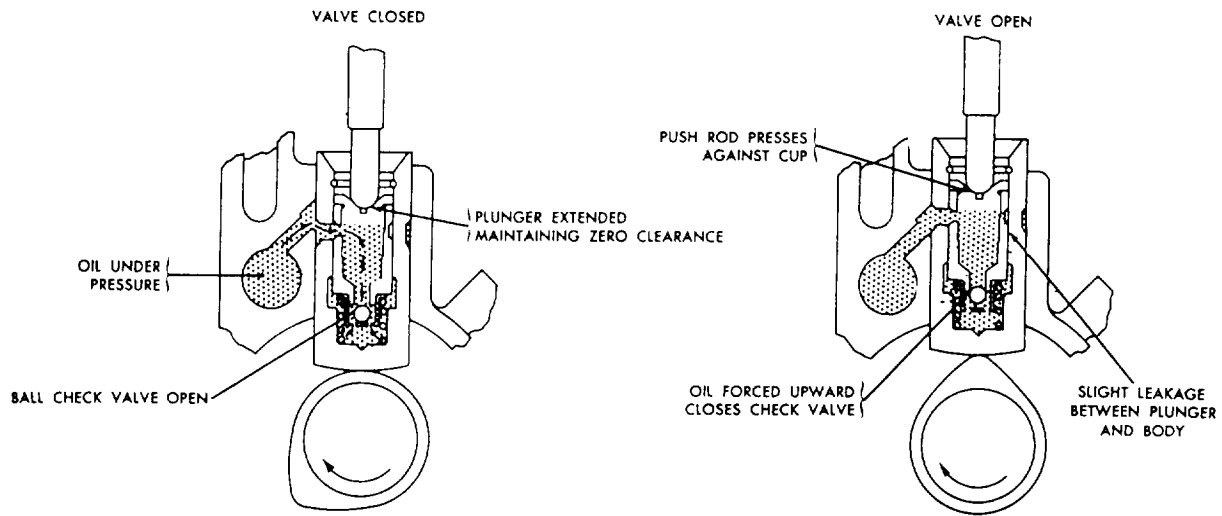Figure 12-25.—Valve operating mechanism for an overhead valve engine.

Figure 12-26.-Operation of a hydraulic valve lifter.

Figure 12-26 shows the operation of one type of hydraulic valve tappet mechanism. Oil under pressure is forced into the tappet when the valve is closed. This pressure extends the plunger in the tappet so that all valve clearance, or lash, is eliminated. When the cam lobe moves around under the tappet and starts to raise it, you hear no tappet noise. The movement of the tappet forces the oil upward in the lower chamber of the tappet. This action closes the ball check valve so that oil cannot escape. Then the tappet acts as though it were a simple, one-piece tappet and the valve is opened. When the lobe moves out from under the tappet and the valve closes, the pressure in the lower chamber of the tappet is relieved. Any slight loss of oil from the lower chamber is replaced by the oil pressure from the engine lubricating system. This oil pressure causes the plunger to move up snugly against the push rod so that any clearance is eliminated.

Timing Gears (Gear Trains)

Timing gears keep the crankshaft and camshaft turning in proper relation to one another so that the valves open and close at the proper time. Some engines use sprockets and chains.

The gears or sprockets, as the case may be, of the camshaft and crankshaft are keyed into position so that they cannot slip. Since they are keyed to their respective shafts, they can be replaced if they become worn or noisy.

With directly driven timing gears (fig. 12-27), one gear usually has a mark on two adjacent teeth and the other a mark on only one tooth. Timing the valves properly requires that the gears mesh so that the two marked teeth of one gear straddle the single marked tooth of the other.

AUXILIARY ASSEMBLIES

We have discussed the main parts of the engine proper; but other parts, both moving and stationary, are essential to engine operation. They are not built into the engine itself, but usually are attached to the engine block or cylinder head.

The fuel system includes a fuel pump and carburetor mounted on the engine. In diesel engines the fuel injection mechanism replaces the carburetor. An
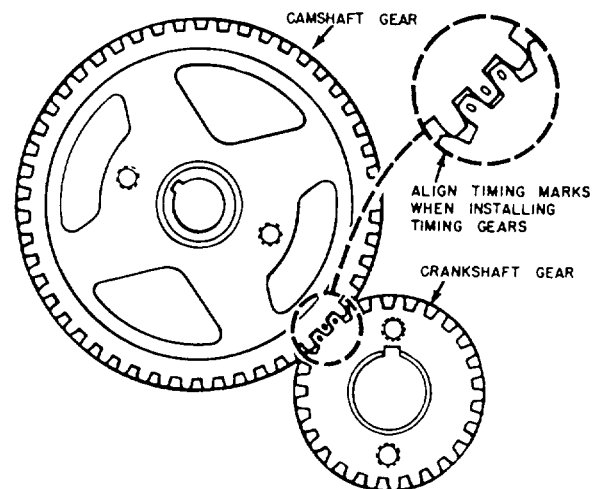

Figure 12-27.-Timing gears and their markings.

electrical system is provided to supply power for starting the engine and for igniting it during operation. The operation of an internal combustion engine requires an efficient cooling system. Water-cooled engines use a water pump and fan while air-cooled engines use a blower to force cool air around the engine cylinders.

In addition, an exhaust system is provided to carry away the burned gases exhausted from the engine cylinders. These systems will not be discussed in this course, however. For further information, refer to NAVPERS 10644G-1, *Construction Mechanic 3 & 2.*

SUMMARY

This chapter explained briefly the following operational principles and basic mechanisms of the internal combustion engine:

The power of an internal combustion engine comes from the burning of a mixture of fuel and air in a small, enclosed space.

The movement of the piston from top to bottom is called a stroke.

To produce sustained power, an engine must repeatedly accomplish a definite series of operations. This series of events is called a cycle.

Engine classifications are based on the type of fuel used—gasoline or diesel.

Design and size must be considered before engine construction.

Engines require the use of auxiliary assemblies such as the fuel pump, the carburetor, and an electrical system.